International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 6, Dec 2019, 1129–1142


# EXPERIMENTAL AND ANALYTICAL EVALUATION OF STRENGTH AND VIBRATION PARAMETERS OF HYBRID MONOCOMPOSITE LEAF SPRING

**SUNEETHA INUGANTI[1], KADIYALA RAVI[2] & N. MOHANA RAO[3]**

[1]*Assistant Professor, Department of Mechanical Engineering, GVPCE, Visakhapatnam, Andhra Pradesh, India*

[2]*Principal, Dhanekula Institute of Engineering & Technology, Ganguru, Vijayawada, Andhra Pradesh, India*

[3]*Professor, Jawaharlal Nehru Technological University, Kakinada, Andhra Pradesh, India*

***ABSTRACT***

***Ever since the spurt in oil prices half a century ago, the focus of automobile designers has been on conservation of fuel. Weight reduction, an important method in this direction, also influences noise level, vibration and ride comfort. Vehicle vibration is essentially a function of road surface profile, vehicle speed and most importantly suspension system. In the present work, mono-composite leaf spring with modified E Glass/epoxy using rubber powder as filler material is designed and analyzed using theoretical calculations and experimental methods. FFt analyzer is used to determine natural frequency and damping ratio of composite leaf spring. All strength parameters are found to be more in modified composite leaf spring when compared to steel and existing composite leaf spring.***

***It is found that for the newly designed spring, there is significant increase of strength parameters. In addition, presence of rubber powder as filler material results in internal damping which leads to significant reduction in vibration.***

***KEYWORDS: Mono Composite Leaf Spring, Rubber Powder, Damping & Vibration***

**Received**: Feb 08, 2019; **Accepted**: Mar 08, 2019; **Published**: Dec 27, 2019; **Paper Id**.: IJMPERDDEC201993

**Original Article**

## 1. INTRODUCTION

Composite materials have been suitably selected to replace with conventional material for more number of automotive components because of advantages like higher strength to weight ratio, higher stiffness to weight ratio, higher fatigue resistance excellent wear and corrosion resistance. To meet the needs of natural resource conservation and energy economy, automobile manufacturers have been attempting to reduce the weight of vehicles. One method of increasing automotive energy efficiency is through mass reduction of standard components by the incorporation of composite material. Significant use of glass reinforced polymer as structural component could yield a 20-30% reduction in vehicle weight. The main function of springs in automotive suspension system is to reduce vibration due to road, irregularities, shock and bump loads. Traditionally, springs are made of metals, which however possess high density, poor corrosive resistance and low strength at high temperature. Many researchers have investigated on fabrication and testing of leaf springs using E-Glass/epoxy, as they have some advantages that metal springs do not possesses.

M Senthil Kumar, S Vijayarangan [1] described static and fatigue analysis of steel and composite leaf spring made up of glass fibre reinforced polymer using life data analysis, and found that stiffness, natural frequency and life of composite leaf spring are higher than those of steel leaf spring. V.K. Aher et al [2] predicted the fatigue life of semi –elliptical steel leaf spring along with analytical and stress deflection calculations using CAE tools. R.B.Charde et al. [3] carried out stress analysis on the graduated leaf in one approach, and in other approach the

stress in master leaf is carried out using finite element analysis. The experimental value obtained by using strain gauge was then validated. They observed that by addition of extra full length leaves, the stresses are reduced drastically. Niklas philipson [4] found the conventional way to model leaf spring, by dividing spring into several rigid links. Preshit B et.al [5] conducted static and modal analysis of leaf spring, using FEA and estimated deflection, stress and mode frequency, induced in the leaf spring with Carbon/epoxy material with orientation angle [-45/45/0/90/45/-45], and concluded that stresses induced in composite leaf spring are much lower than those of steel leaf spring.

P Srinivas Rao et.al [6] conducted modal and harmonic analysis with multi leaf spring for different materials and compared with theoretical analysis, and concluded that composite materials E Glass/epoxy and Carbon/Epoxy have high amplitude of response than other materials. Malaga et al [7] replaced multi leaf spring by mono-composite leaf spring for same load carrying capacity and high strength to weight ratio. I Rajendran and S Vijayarangan [8] presented an artificial genetic algorithm approach for design optimization of composite leaf spring. The design variables (thickness and width) of steel and composite leaf springs are optimized by making use of GA, which contributed an8% weight reduction in steel leaf spring and 23.4% in composite leaf spring.H.A. Al quershi [9] has described a single leaf variable thickness spring of Glass fibre reinforced plastic. A multi leaf spring with similar mechanical and geometrical properties was designed, fabricated and tested. G Shivsankar et al [10] designed, analyzed, fabricated and tested unidirectional Glass fibre /epoxy mono-composite leaf spring without end joints and with end joints. They found that stresses are much lower, natural frequencies are higher and spring weight is nearly 85% lower. M Shokrieh, and Rezaei [11] analyzed four leaf steel leaf spring to optimize for spring weight. They showed that an optimum spring width decreases hyperbolically, and the thickness increases linearly from the spring eyes towards the axle seat.

It is inferred that hybrid composites with an additive can improve the applications of composites in the field of automobile. In present work, a mono-composite leaf spring with modified E-Glass/epoxy using filler material is designed to replace an existing leaf spring. The stress, deflection and natural frequency are determined using analytical calculations and are compared with experimental values.

## 2. SPECIFICATIONS OF EXISTING LEAF SPRING

The figure 1 shows multi leaf spring of the suspension system of a light motor vehicle.

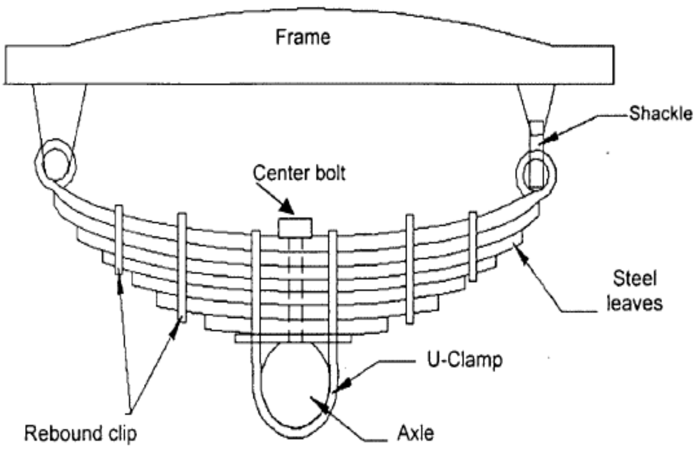



**Figure 1: Conventional Suspension System.**

Keeping the specification for modified hybrid composite leaf spring same as that of steel spring, it is designed to replace the seven leaf steel spring.

Specifications of existing steel leaf spring of Mahindra commander vehicle are taken, as given below in table 1.

**Table 1: Parameters of Steel Leaf Spring**

| Parameter | Value |
|---|---|
| Distance between eyes | 1220 mm |
| Camber | 120mm |
| Width | 60mm |
| Thickness | 7mm |
| Max load on each spring | 3625N |
| No of leaves | 10 |

## 3. DESIGN OF MONOCOMPOSITE LEAF SPRING

As composite materials are proved to be suitable substitution in connection with weight reduction, these have been selected. The E glass fibre with modified resin using 6% of rubber powder has been selected as material for hybrid mono composite leaf spring, based on characterization of all specimens

## 4. EVALUATION OF MECHANICAL PROPERTIES

The mechanical testing was carried out using a Universal testing machine (9036 TD Sr no STS -22), as shown in figure 2. The specimens are prepared according to ASTM D as shown in figure 3. The test was conducted on all specimens to obtain tensile strength and modulus of elasticity (1mm/min speed). The obtained stress strain diagram is as shown in figure 4.

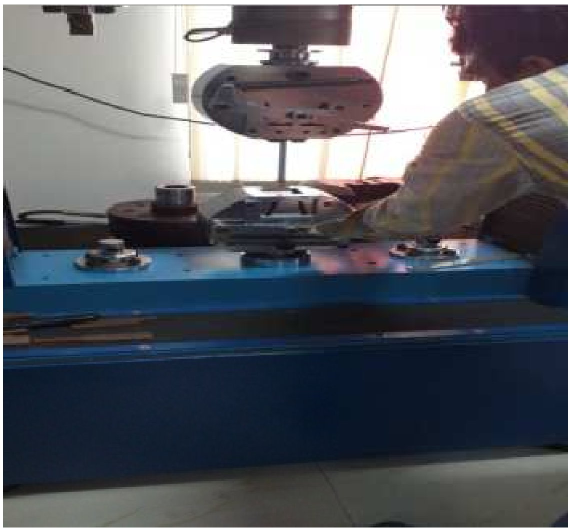


**Figure 2: UTM used for Tensile and Flexural Strength.**

**Figure 3: Specimens After Tensile Testing.**

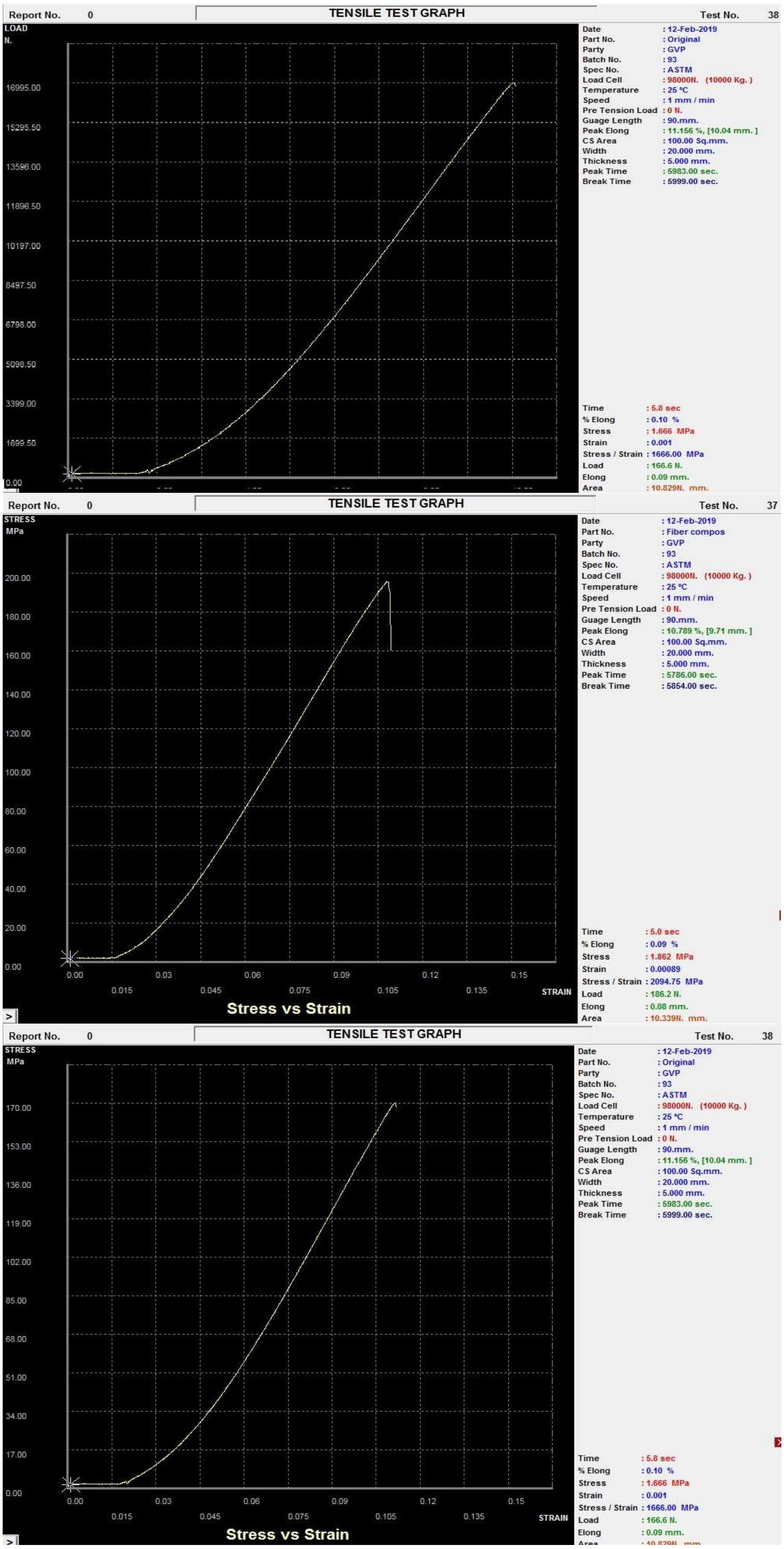



**Figure 4: Stress Strain Diagrams.**

The obtained material properties are given in table 2.

**Table 2: Modified Hybrid E Glass/Epoxy Properties**

| Parameter | Value |
|---|---|
| Tensile modulus in longitudinal direction ($E_x$) | 55700MPa |
| Tensile modulus in transverse direction ($E_y$) | 7200MPa |
| Tensile modulus along Z direction ($E_z$) | 7200MPa |
| Tensile strength along longitudinal direction $\sigma_{xt}$ | 1852MPa |
| Tensile strength in transverse direction $\sigma_{yt}$ | 120MPa |
| Shear strength along XY plane | 100MPa |
| Modulus of rigidity along XY plane ($G_{xy}$) | 3200MPa |
| Modulus of rigidity along YZ plane ($G_{yz}$) | 1725MPa |
| Modulus of rigidity along XZ plane ($G_{zx}$) | 3200MPa |
| Poisson ratio XY plane ($\upsilon_{xy}$) | 0.23 |
| Poisson ratio YZ plane ($\upsilon_{yz}$) | 0.32 |
| Poisson ratio XZ plane ($\upsilon_{xz}$) | 0.23 |
| Density of the material ($\rho$) | 1850kg/m$^3$ |

## 5. DESIGN REQUIREMENTS

Assuming that the design requirements are same as that of steel leaf spring, the present work aims at replacing seven leaf spring for suspension of light passenger vehicle with modified hybrid mono-composite leaf spring. The values are given as follows.

**Table 3**

| Parameter | Value |
|---|---|
| Full bump load | 7125N |
| Load on each leaf spring | 3563N |
| Maximum Deflection | 80mm |
| Distance between eyes | 1220mm |
| Camber of spring | 120mm |

### 5.1 Selection of Design Method

Considering the behavior of leaf spring as simply supported beam with three point bending, which is subjected to bending stress as well as transverse shear stress. Flexural analysis can be done based on three design possibilities that are constant thickness, varying width; constant width, varying thickness; constant cross section. Constant cross-section design is used, which accommodates continuous reinforcement of fibres and quite suitable for hand-lay-up technique". The material properties considered in this work are shown in table 4.

**Table 4: Mechanical Properties of Materials**

| Parameter | Steel | E Glass/Epoxy | Modified E Glass/Epoxy |
|---|---|---|---|
| | 210X10$^3$ (MPa) | 34000 (MPa) | 55700MPa |
| Tensile modulus in transverse direction ($E_y$) | 210X10$^3$(MPa) | 6530 (MPa) | 7200MPa |
| Tensile modulus along Z direction ($E_z$) | 210X10$^3$(MPa) | 6530 (MPa) | 7200MPa |
| Tensile strength along longitudinal direction $\sigma_{xt}$ | 1680-1920(MPa) | 900 (MPa) | 1852MPa |
| Tensile strength in transverse direction $\sigma_{yt}$ | | 35 (MPa) | 120MPa |
| Shear strength along XY plane | | 90 (MPa) | 100MPa |
| Modulus of rigidity along XY plane ($G_{xy}$) | | 2433 (MPa) | 3200MPa |
| Modulus of rigidity along YZ plane ($G_{yz}$) | | 1698 (MPa) | 1725MPa |
| Modulus of rigidity along XZ plane ($G_{zx}$) | | 2433 (MPa) | 3200MPa |
| Poisson ratio XY plane ($\upsilon_{xy}$) | 0.3 | 0.217 | 0.23 |
| Poisson ratio YZ plane ($\upsilon_{yz}$) | | 0.366 | 0.32 |
| Poisson ratio XZ plane ($\upsilon_{xz}$) | | 0.217 | 0.23 |
| Density of the material ($\rho$) | 7800 kg/m$^3$ | 2000 kg/m$^3$ | 1852kg/m$^3$ |

## 6. THEORETICAL ANALYSIS

The following figure shows the free body diagram of leaf spring, which includes forces and moments acting on the member.

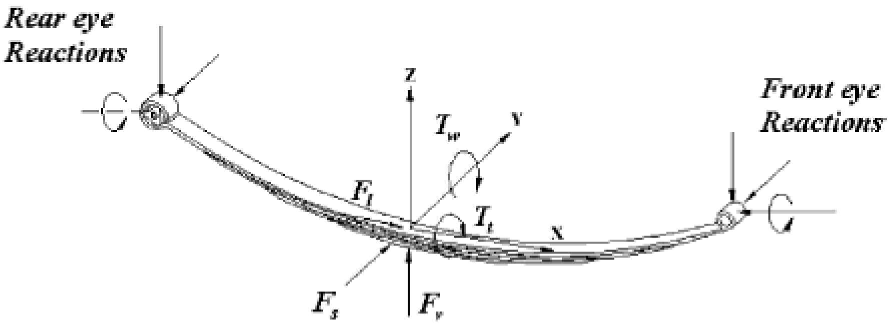



**Figure 5: Force on Leaf Spring.**

Fx = Horizontal force produced by change in linear momentum of vehicle during the brake

or accelerating (max longitudinal force = 3000N)

Fy = Vertical force = Full bumpload /2

Fz = Side load reduced by the change in angular momentum.

(Assumed to be 75% of vertical load)

- [Q] is obtained as follows

$$(Q) = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix}$$

$$(Q_{11}) = \frac{E_1}{1-\vartheta_{12}\vartheta_{21}}$$

$$(Q_{22}) = \frac{E_2}{1-\vartheta_{12}\vartheta_{21}}$$

$$(Q_{12}) = \frac{\vartheta_{21}\, E_2}{1-\vartheta_{12}\vartheta_{21}}$$

$$\begin{Bmatrix} m_{xx} \\ m_{yy} \\ m_{xy} \end{Bmatrix} = -\begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2 \\ \partial^2 w/\partial z^2 \end{Bmatrix}$$

$D_{11}= Q_{11}\frac{h^3}{12}$ ;$D_{12}=Q_{12}\frac{h^3}{12}$; ;$D_{22}=Q_{22}=\frac{h^3}{12}$;;$D_{66}=Q_{66}\frac{h^3}{12}$;and $D_{16}= D_{26}=0$

$$\begin{Bmatrix} \frac{\partial^2 w}{\partial x^2} \\ \frac{\partial^2 w}{\partial y^2} \\ \frac{\partial^2 w}{\partial z^2} \end{Bmatrix} = -\begin{bmatrix} D_{11}^* & D_{12}^* & D_{16}^* \\ D_{12}^* & D_{22}^* & D_{26}^* \\ D_{16}^* & D_{26}^* & D_{66}^* \end{bmatrix} \begin{Bmatrix} M_{xx} \\ M_{yy} \\ M_{zz} \end{Bmatrix}$$

$D_{11}^*= (D_{22}D_{66})D^*$; $D_{12}^*= (-D_{12}D_{66})D^*$

$D^*_{22}$= ($D_{11}D_{66}$)$D^*$

$D^*_{66}$= ($D_{11}D_{22}$-$D_{12}D_{12}$)/$D^*$

$D^*$=($D_{11}D_1$-$D_{12}D_2$)

$D_1$= $D_{22}D_{66}$ ; $D_2$=(- $D_{12}D_{66}$) ; $D_3$=$D_{12}D_{26}$

$$\sigma^k_{x\,x} = \frac{q_0.xZ}{2}\left(\bar{Q}_{11}{}^{k}D_{11}{}^{*} + \bar{Q}_{12}{}^{k}D^*_{12} + \bar{Q}_{16}{}^{k}D^*_{16}\right)$$

$$\frac{\partial^2 w}{\partial x^2} = -D_{11}{}^{x}M_{xx}$$

$$\frac{\partial^2 w}{\partial\, y^2} = -D_{12}{}^{x}M_{xx}$$

$$2\frac{\partial^2 w}{\partial x \partial\, y} = -D_{16}{}^{x}M_{xx}$$

The constitutive equations for anisotropic laminate are given by

$$\begin{Bmatrix} \{N\} \\ \{M\} \end{Bmatrix} = \begin{bmatrix} \{A\} & \{B\} \\ \{B\} & \{D\} \end{bmatrix} \begin{Bmatrix} \{\epsilon\} \\ \{k\} \end{Bmatrix}$$

$$[A] = \sum_{n=1}^{k} Qk(Z_k - Z_{k-1})$$

$$[B] = \sum_{k=1}^{n} [Q_{ij}]^k d_k \bar{Z}_k$$

$$[D] = \sum_{k=1}^{n} Q^k{}_{ij}\left[dk\bar{Z}_k{}^2 + \frac{dk^3}{12}\right]$$

The stresses and strains are obtained by using following expressions

$$\begin{Bmatrix} \epsilon x^0 \\ \epsilon y^0 \\ \epsilon s^0 \end{Bmatrix} = \begin{Bmatrix} axx & axy & axs \\ ayx & ayy & ays \\ asx & asy & ass \end{Bmatrix} \begin{Bmatrix} N_x \\ N_y \\ N_s \end{Bmatrix}$$

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{Bmatrix} Q_{11} Q_{12} & 0 \\ Q_{21} Q_{22} & 0 \\ 0 \;\; 0 & Q_{66} \end{Bmatrix} \begin{Bmatrix} \epsilon x^0 \\ \epsilon y^0 \\ \epsilon s^0 \end{Bmatrix}$$

Where,

$$[a] = [A]^{-1}[b] = [A]^{-1}[B][d]$$

$$[d] = [(D)-(B)[A]^{-1}(B)]^{-1}$$

Natural frequency of composite leaf spring can be obtained by using following equation

$$\omega_i = \lambda_i^2\sqrt{\frac{EI}{\rho A}} \qquad \lambda_i = 1.875, 4.694, 7.85, 10.996, 14.137.$$

### 6.1 Results

The following table gives the calculated strength parameters based on theoretical formulae of newly designed composite leaf spring and comparison with conventional steel, and the existing E Glass epoxy is also shown.

**Table 5: Comparative Theoretical Analysis of Strength Parameter of Leaf Spring**

| Sl. No. | Parameter | Steel | E-Glass/epoxy | Modified E-Glass/epoxy |
|---|---|---|---|---|
| 1 | Max stress (N/mm$^2$) | 723 | 316.54 | 235.34 |
| 2 | Deflection (mm) | 134.7 | 79.6 | 61.5 |
| 3 | Stiffness (N/mm) | 22.32 | 29.35 | 28.64 |
| 5 | Natural frequency (Hz) | 10 | 16 | 19 |

The dimensions are checked against Tsai failure theory and found to be safe. In order to validate the analytical results, the strength parameters are also determined using experimentation.

## 7. EXPERIMENTAL WORK

The fabrication of mono-composite leaf spring using design parameters obtained from numerical analysis has been done, using hand-layup technique. The wooden mould as per the shape of leaf spring is prepared. In the conventional hand-lay-up technique, a releasing agent was applied uniformly to the mould which has good surface finish, followed by the uniform application of the epoxy resin. Started laying up the first ply and applied the matrix on it again. The glass fiber cloth was placed on a leveled surface and any entrapped air between the cloth and surface was removed. Other layers was arranged and a roller was used to remove all the trapped air. As shown in figure 6, simultaneous laying of laminas on the mould was done to get the required thickness, for 15mm thickness 30 layers of 0.5mm thickness was used in present work. In between the layers, resin mixture was poured and rolled out by using rollers to remove the entrapped air bubbles. After process of laying the laminas, a cover plate was placed on entire laminate. The whole assemble was allowed to get cured at room temperature for 72hrs, and a constant load of 50kg was applied.- The part is discharged from the mould without making any harm to segment. Finally, the laminate was trimmed, to get the required dimensions which is shown in figure 7.

**Figure 6: Fabrication Process.**

**Figure 7: Fabricated Spring with Eye Joints.**

### 7.1 Static Test

In order to obtain load deflection data and spring rate data, the spring is loaded from zero to maximum deflection and vice versa, using hydraulic test rig as shown in figure 7. The data obtained from experiment is shown in table 5. The comparative analysis between strength parameters of these three materials is shown in table 6.

**Figure 7: Hydraulic Test Rig used for Static Test.**

**Table 6: Load Deflection Data of Leaf Spring with Different Materials**

| Material | | Steel [8] | | E Glass epoxy | | Modified E Glass/epoxy | |
|---|---|---|---|---|---|---|---|
| Sl No. | Deflection (mm) | Load (N) | Spring Rate (N/mm) | Load (N) | Spring Rate (N/mm) | Load (N) | Spring Rate (N/mm) |
| 1 | 5 | 125 | 25 | 150 | 30 | 112 | 22.4 |
| 2 | 10 | 235 | 23.5 | 260 | 26 | 250 | 25 |
| 3 | 15 | 340 | 22.66 | 440 | 29.33 | 360 | 24 |
| 4 | 20 | 520 | 26 | 560 | 28 | 500 | 25 |
| 5 | 25 | 600 | 24 | 640 | 25.6 | 680 | 27.2 |
| 6 | 30 | 726 | 24.2 | 800 | 26.66 | 876 | 29.2 |
| 7 | 35 | 822 | 23.48 | 900 | 25.71 | 1015 | 29 |
| 8 | 40 | 941 | 23.52 | 1150 | 28.75 | 1152 | 28.8 |
| 9 | 45 | 1075 | 23.88 | 1290 | 28.66 | 1341 | 29.8 |
| 10 | 50 | 1177 | 23.54 | 1400 | 28 | 1380 | 27.6 |
| 11 | 55 | 1386 | 25.2 | 1520 | 27.63 | 1573 | 28.6 |
| 12 | 60 | 1452 | 24.2 | 1650 | 27.5 | 1785 | 29.74 |
| 13 | 65 | 1543 | 23.73 | 1780 | 27.38 | 1863 | 28.65 |
| 14 | 70 | 1658 | 23.68 | 1930 | 27.57 | 1921.5 | 27.45 |
| 15 | 75 | 1724 | 22.9 | 2000 | 26.6 | 2231.25 | 29.75 |

The following figure 8 shows graphs drawn load vs. deflection and spring rate vs. deflection.

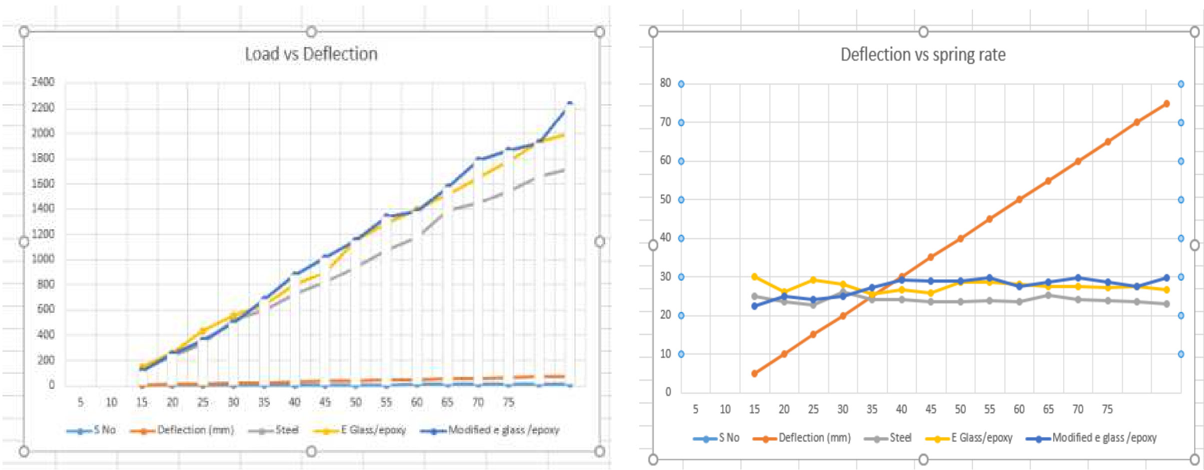



**Figure 8: Graphs based on Experimental Test.**

**Table 7: Experimental Data of Stress, Deflection and Stiffness of Leaf Spring for Different Materials**

| Parameter | Max Load | Max Stress ($N/mm^2$) | Deflection(mm) | Stiffness | Mass of Spring(kg) |
|---|---|---|---|---|---|
| Steel | 3320 | 680.34 | 132.6 | 20.64 | 34.5 |
| EGlass/epoxy | 3320 | 298.75 | 78 | 29.67 | 3.34 |
| Modified E Glass/epoxy | 3320 | 216.53 | 55 | 28.75 | 2.01 |

### 7.2 Vibration Test

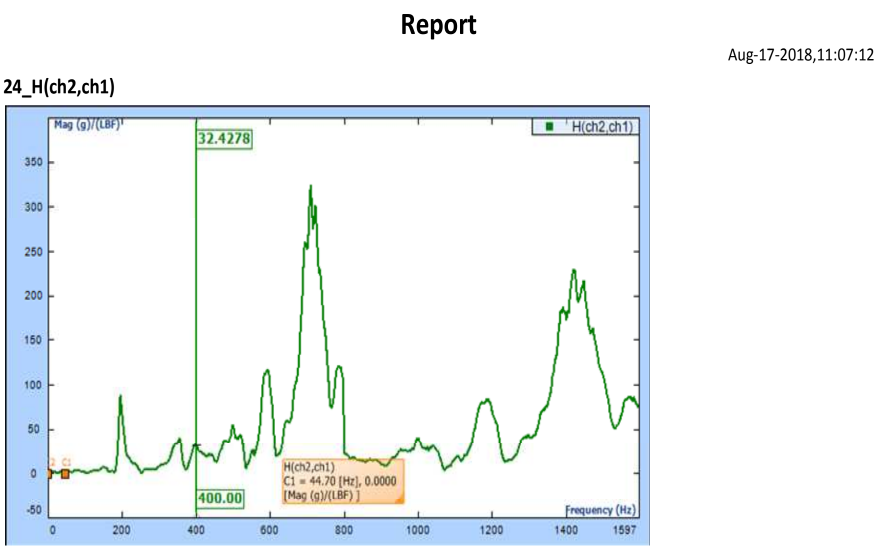
In this work, an attempt to reduce vibrations is done by improving internal damping, using rubber powder as filler material for Glass fibre reinforced composite leaf spring. The prepared composite leaf spring is tested for vibration parameters using FFT analyzer which is shown in figure 9.

The accelerator is placed at the center of the composite leaf spring to obtain response curves.

**Figure 9: Damping Test of Leaf Spring using FFT Analyzer.**

### 7.3 Results

The displacement versus natural frequency graph is plotted. For each space, data given by FFT analyzer in the form of amplitude versus natural frequency graph was taken for study. The obtained screen data is shown in figure 10. The natural frequency and damping ratio obtained from test is shown in table 8.



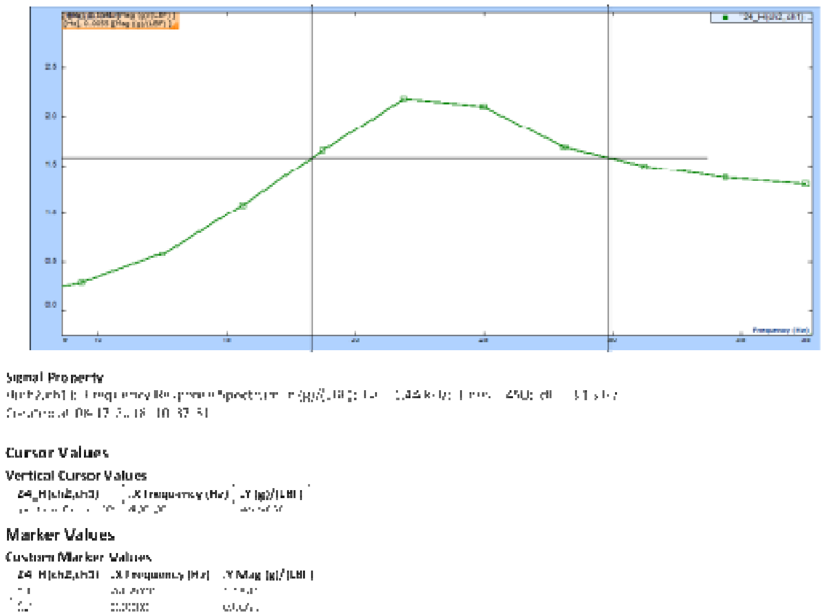



**Figure 10: Response Curve Obtained from Vibration Test.**

At 1st peak

$f_1$ = 18Hz; $f_2$ = 30Hz $\xi = \frac{30-18}{30+18} = 0.25$

At 2nd peak

$f_1$ = 292Hz; $f_2$ = 484Hz

$\xi = \frac{484-292}{484+292} = 0.247$

**Table 8: Experimental Values of Natural Frequency and Damping Ratio**

| | Natural Frequency (Hz) | Damping Ratio |
|---|---|---|
| Steel | 8 | 8% |
| E Glass/epoxy | 16 | 25% |
| Modified E Glass/epoxy | 22 | 32% |

## 8. DISCUSSIONS

A Comparative analysis between experimental and theoretical for all parameters like max stress, deflection, natural frequency and damping ratio has been done and values are shown in table 9.

**Table 9: Comparison between Experimental Values and Theoretical Values**

| | Max Stress (N/mm$^2$) | | | Max Deflection (mm) | | | Natural Frequency (Hz) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Analytical | Experimental | Deviation | Analytical | Experimental | Deviation | Analytical | Experimental | Deviation |
| Steel | 723 | 680.34 | 5.9 | 134.7 | 132.6 | 1.5 | 10 | - | - |
| E Glass/epoxy | 316.54 | 298.75 | 5.6 | 79.6 | 75 | 5.7 | 16 | 19 | 1.8 |
| Modified E Glass/epoxy | 235.34 | 216.53 | 8.07 | 61.5 | 55 | 10.5 | 28 | 32 | 14.2 |

## 9. CONCLUSIONS

- Mono composite leaf spring with modified epoxy has been designed to replace existing steel, E Glass/epoxy material.
- Designed leaf spring has been fabricated using hand layup technique.
- Stress, deflection, stiffness and natural frequency have been calculated using analytical calculations.
- Experimental test to find max stress, deflection and stiffness using UTM was carried out, and it is found that there is a variation between experimental and theoretical values. It is found that max stress for newly designed spring is 68.1 % less compared to conventional steel and 27.5% less compared to existing E Glass/epoxy. The max deflection for newly designed spring is 58.5% less compared to conventional steel and 29.4% less compared to existing E Glass/epoxy. The natural frequency for newly designed spring is 175 % more compared to conventional steel and 37.5% more compared to existing E Glass/epoxy. Damping ratio for newly designed spring is more compared to conventional steel existing E Glass/epoxy.
- Vibrations have been greatly reduced in new designed composite leaf spring.

***REFERENCES***


1. *Mouleeswarn Senthil Kumar, Sabapathy Vijayarangan, "Analytical and experimental studies on fatigue life prediction of steel and composite multi leaf spring for light passenger vehicle using Life data analysis"-ISSN 1392-1320; Material Science vol 13 No 2 2007.*
2. *V.K. Aher et.al, "Static and fatigue analysis of multi leaf spring used in the suspension system of LCV" International journal of engineering and applications, ISSN: 2248-9622; vol-2 Issue 4; july-aug 2012 [1786-1791].*
3. *Jain, V., & Sharma, T. (2013). Analysis of Leaf Spring Conditions for Heavy Duty Vehicle. International Journal of Automobile Engineering Research and Development (IJAuERD), 3(1), 97–104.*
4. *R. B Charde ,Dr D.V Bhope ," Investigations of stresses in master leaf of leaf spring by FEM and its experimental verification , " International journal of engineering science and technology vol 4; No 2 feb 2012 ISSN 0975-5462.*
5. *Niklas philipson ," Leaf spring modeling" Ideon science park , SE 22370 Lund,Swede Modellica 20-06.*
6. *Preshit B Waghurene et.al "Staticand modal analysis of leaf spring using FEA" International journal of technical research and applications. volume 3 Jan-feb 2015.*
7. *Kesavarao, Y., Ramakrishna, C., & Arji, A. (2015). Stress Analysis of Laminated Graphite/Epoxy Composite Plate Using FEM.*
8. *Putta srinivas rao, Revu Venketesh "Modaland harmonic analysis of leaf spring using compositematerial", International journal of novel research in electrical and mechanical engineering vol 2 issue-3 sep–dec 2003*
9. *Malaga Anil Kumar, T. N. Charyul et. al" Design optimization of leaf spring" International journal of Engineering Research and applications, vol-2; Issue 6 Nov-dec 2012.*
10. *I Rajendran, S Vijayarangan, "Optimal design of a composite leaf spring using genetic algorithms" composites and structures 79.*
11. *Mishra, A. (2016). Overview study of the machining of composite materials. Impact J, 4(7).*

12. *H A Al Quershi"Automobile leaf springs from composite materials", Journal of material processing technology, vol 118 PP J8-61.*
13. *Gulur siddamana, Shivsankar et.al. "Mono composite leaf spring for light vehicle-Design end joint analysis and testing "International journal of material science vol. 12.*
14. *Mahmood M Shokrieh, Davood Rezaei "Analysis and optimization of a composite leaf spring" composite structures 60 (2003) 317–325.*


**AUTHORS PROFILE**

**Inuganti Suneetha**, is a part time research scholar in the mechanical engineering department at University college of Engineering Kakinada, Kakinada India. She completed her post graduation in machine design and currently she is working in the area of composite materials and vibration analysis of composite beams.

**Kadiyala Ravi**, received his Ph.D in the area of alteranate fuels From University college of engineering, Andhra university, Visakhapatnam, India in 2006. Now he works as Principal, Dhanekula institute of Engineering & Technology, Ganguru, Vijayawada, Andhra Pradesh. His current research area includes alternate fuels, composite materials and vibrations.

**Mohanarao Nalluri,** received his Ph.D in the area of Robot kinematics from University college of engineering Kakinada, Kakinada India in 2008. Now he works as a professor in Mechanical Engineering Department at University college of Engineering Kakinada, JNTUK. His current research includes free vibration analysis of structure, robot kinematics and mechanism and composites.